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AN INVESTIGATION OF METHODS AND POSITIONS USED IN MANUAL QUALITY PICKING OF SMALL OBJECTS

A THESIS

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AN INVESTIGATION OF METHODS AND POSITIONS USED IN MANUAL QUALITY PICKING OF SMALL OBJECTS

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ABSTRACT

The purpose of this study was to determine the optimum picking method and picking position which should be used in the manual quality picking of small objects. This investigation was part of a research project begun at the Georgia Institute of Technology in 1950 under the direction of Dr. J. J. Moder.

The data used was obtained from nine experimental subjects. They were chosen from a class of 44 students divided into three strata according to their total raw scores on the Purdue Pegboard Aptitude Test for manual and finger dexterity. The experiments were conducted in the laboratory of the School of Industrial Engineering, utilizing a specially constructed picking conveyor. The objects used were Great Northern beans containing 4 per cent (by weight) Pinto beans which represented the defective objects.

The following factors were held constant throughout the experiments:

1. Rate of Flow
2. Belt Speed
3. Belt Density
4. Damage Content
5. Illumination
6. Work - Surface Height
7. Operator Posture
8. Operator Pace

A factorial mixed model experiment was employed to test the effect of the following independent variables upon the

operators' performance:

1. Nine operators
2. Three picking methods
   a. The "roll" method
   b. The "pick and throw - multiple object" method
   c. The "pick and throw - single object" method
3. Three picking positions
   a. Side position (right)
   b. Side position (left)
   c. End position
4. Two replications

The following dependent variables were used to measure the operators' performance:

1. Net Picking Rate
2. Picking Quality Rate

From a statistical analysis of the experimental data the following conclusions were drawn:

1. The two "pick and throw" methods proved to have statistically significant greater net picking rate than the "roll" method. However, the "roll" method had a better picking quality rate than either of the other methods.

2. None of the picking positions had a significant effect upon either of the dependent variables.

3. The experimental data was also classified according to the operator's dominant hand. It was found that left-handed operators picked as well at all positions as right-handed operators.

4. It was also found that the Purdue Pegboard Test score was not a valid predictor of an operator's net picking rate for this particular group of subjects.

For ease of understanding, all further references to manual quality picking will be specifically related to the peanut processing industry. Because of similar equipment, techniques, and labor, it is felt that the results of this study may be applied generally to manual quality picking operations throughout the food processing industry.

Statement of the Problem.--Moder and Penny made an extensive survey of the peanut processing industry.[4] Among other things brought out in their report was a recommendation for a thorough analysis of the costly manual quality picking operation. Calhoun made an exploratory study of those factors which seem most likely to affect manual quality picking.[5] Zimmer made a detailed investigation of those factors which Calhoun found significant.[6] This thesis is based upon the results of those earlier investigations and is an attempt to provide a more refined basis for the selection of optimum manual quality picking conditions.

CHAPTER II

PRESENT STATUS OF THE PROBLEM

This chapter is divided into three major sections. The first section deals with a brief description of the manual quality picking operation, and the means by which it was measured during this study. The second section presents those factors affecting operator performance which were considered in the course of this investigation. The last section is concerned with a discussion of the previous research done at the Georgia Institute of Technology on manual quality picking of small objects.

Description of the Manual Quality Picking Operation

Manual quality picking is essentially an inspection operation. It requires the operator to make a continuous series of mental acceptance or rejection type decisions.

In industry it is the usual practice for the operators to sit or stand at the side of a continuously moving conveyor belt. Upon this belt are placed the products which are to be inspected for defectives. The defectives are dispersed at random among the vast mass of good products. As a section of the belt is presented to the operator's view, the defective objects are picked out and placed aside. The operator is not expected to pick out all he can see, but only as many as he can pick from his own position. Also it is expected that operators will mistakenly pick out some good objects instead of defectives.

There are two means of measuring operator performance which are used throughout this thesis. The first of these is the Net Picking Rate which is found by the following formula:

Total Number of Pickouts per Minute (or Gross Rate) Less the Number of Good Objects Picked per Minute (or Picking Errors) = Net Picking Rate

The other measure used to evaluate operator performance is the Picking Quality Rate which is the number of good (non-defective) objects picked per minute instead of defective objects. The picking quality rate is also known as the Error Rate; a high level denotes poor operator quality.

Factors Which Affect Operator Performance

Approach to the Problem.--One might assume that this operation would lend itself to treatment by conventional motion and time study technique. However, a deeper analysis of the manual quality picking operation disputes this assumption. Malcolm and DeGarmo have stated quite reasonable objections to the use of conventional work study techniques as applied to this problem.[7]

Therefore, in attacking the problem of manual quality picking, it is most desirable to set forth those factors which affect the picking rate and picking quality rate. Once these factors are ferreted out and their importance established, then a controlled relative experiment can be performed, which will determine the optimum level of the factor involved.

The above method of attack is the same as that used by Calhoun and Zimmer.[8 9] The factors explored in this investigation are those which they proved to have a significant effect on the operators' picking rate. Each factor will be discussed individually.

Operator.--Calhoun found that there was a significant difference in the operator pickout rate. There was a difference of 14.2 per cent in the picking rate between his fastest and slowest operators.[10] Zimmer found a difference of 19.8 per cent between the most and the least successful operators.[11]

Zimmer felt that previous research justified an attempt to devise aptitude testing procedures for the selection of operators best suited for quality picking. He states that the visual-reaction-decision time and the manipulative skill of the operator are the two principal factors which account for the large differences in operator picking rates.[12]

Pace.--This factor is important in any experiment in which the human element is a source of variation. It is very difficult, if not almost impossible, to measure operator pace precisely. Therefore, the experimenter can only use the relative measures of normal and maximum pace. Calhoun had his operators work at their normal pace.[13] Wadsworth meanwhile found that performing a task at a very fast speed results in less variation in time (inconsistency) than at a lower speed.[14] Zimmer therefore required his operators to work at a brisk pace.[15]

Fatigue.--This is another source of operator variation which is difficult to measure either in absolute or relative terms. It is felt that with short runs (three minutes duration) fatigue will be at a minimum. However, fatigue will have some effect on the operators' performances for the complete replication. Therefore, in this study it is assumed that all operators will be affected by fatigue to the same extent; and any differences due to fatigue will be included in the residual error of the experiment.

Work-Surface Height.--This factor was standardized by Calhoun at approximately three inches below the elbow as recommended by Barnes and Ellis.[16 17 18] Considering the work done by Barnes and Ellis, it is felt that optimum results will be obtained by continuing this standard.

Illumination.--There must be enough illumination on the work place so that the operators' minimum visual impression time is less than the time the object is within his field of vision.[19] For best results in an inspection operation, 30 to 100 foot candles are recommended.[20]

Picking Position.--This is determined by the operator's position in relation to the picking belt and the direction of flow of objects as follows:

1. Right Side Position - The operator stands facing perpendicularly to the conveyor with the objects moving from left to right across his field of vision.

2. Left Side Position - The operator stands facing perpendicularly to the conveyor with the objects moving from right to left across his field of vision.

3. End Position - The operator stands at the end of the conveyor with the objects moving towards his field of vision.

Malcolm and DeGarmo found the end position to be superior.[21] However, they did not use a controlled experiment to reach this conclusion. Moder also found the end position to be superior.[22] However, he included a change in the picking method when testing the end position. Because none of these authors treated the picking position in a completely rigorous manner further research on the subject was necessary.

Calhoun on the other hand used two of these position, viz. Right Side and End, in a controlled factorial experiment.[23] He found that for only one of his four operators was the picking position a significant source of variation in the per cent of good objects placed in the pickouts.[24]

Also, the picking position did not affect the operators' picking rate significantly.[25] However, Calhoun found that in combination with fixed levels of other factors the side position was superior.[26] Therefore, from an industrial operational point of view he recommended the side position.

Zimmer accepted Calhoun's findings and used the side (right) position only.[27]

Picking Method.--There are two picking methods which are in use today. A third method has been developed experimentally as a modification to one of these. The three methods will be discussed separately.

1. "Roll" method - This is the method most prevalent in industry at present. With this method, the operator grasps the objects with the thumb and forefinger, rotates the hand and releases the object into the palm. These motions are repeated until the hand is full and the objects are placed aside.

2. "Pick and Throw (Multiple object)" method - This method was developed by Dwyer.[28] Calhoun tested the method experimentally, and found that it was superior to the "roll" method, resulting in an 8.6 per cent increase in picking rate with little decrease in picking quality.[29] On the basis of Calhoun's results, Zimmer used only this method for his investigation.[30] Essentially this consists of grasping one object in the fingertips and then grasping a second object in the fingertips without palming. Two or three objects may be picked in this manner, and are then tossed aside with a simple wrist motion.

3. "Pick and Throw (Single object)" method - This is a modification of the "pick and throw" method discussed above. It is basically the same except that the operator grasps only one object in his fingertips and then disposes of it immediately. This method was developed with the viewpoint that the additional disposal movement time incurred is less than the time lost in fumbling and grasping several objects in the fingertips at one time.

All of the above methods are executed as two-handed simultaneous motions. There is no restriction upon grasping more than one object at a time if they lie adjacent to each other, except that when using the third method only one object may be grasped. All three methods can be employed at any picking position.

Rate of Flow of Objects.--Zimmer established this factor in the following manner:[31]

> One measure of the rate of flow is the weight of objects passing an operator per unit of time. This measure can be defined by the following equation:

$$\text{Rate of Flow (lbs/min)} = \text{Belt Speed (ft/min)} \times \text{Belt Width (ft)} \times \text{Relative Density of Objects on Belt} \; \frac{\text{Wt. of Objects/sq.ft (amount of objects actually on the belt)}}{\text{Wt. of Objects/sq.ft (for 100\% coverage of the belt)}} \times \text{Weight of Objects (lbs/sq.ft)}$$

Using a constant rate of flow and a fixed belt width, Zimmer determined four combinations of density and belt speed which he used in his investigation. These density-belt speed combinations ranged from 100 per cent and 10 feet per minute to 10 per cent and 100 feet per minute.[32]

Zimmer's results showed that the density-belt speed factor had the greatest effect on the picking rate. The second combination of 25 per cent density and 40 feet per minute was found to be the best of the combinations tested. This level resulted in a 5.4 per cent higher picking rate than the next best combination.[33]

From his experimental data he determined graphically optimum levels of density and belt-speed at 21.8 per cent and 46 feet per minute.[34] These findings were for one rate of flow only (7.75 lbs/min).

Damage Content.--The damage content is the weight ratio of visibly damaged objects to the total number of objects expressed as a percentage. Calhoun used three damage contents in conjunction with five densities. He combined them so as to have only two levels of per cent defective objects on the picking belt. He further divided each of these levels into three so-called belt loadings: high, medium, and low.[35] He found the low-belt loadings gave the greatest single improvement in the picking rate.[36] The true effect of damage content on the picking rate in his experiment is difficult to assess since he confounded damage-density levels with belt loadings. However, since both of the low-belt loading combinations contained a 4 per cent damage content, it is safe to assume that this level was the optimum for his investigation.

Zimmer utilized damage content as an independent variable in his study.[37] He found that the high (4 per cent) damage content consistently resulted in a higher picking rate and better picking quality than did the low (2 per cent) damage content for all conditions. The grand average differences between the high and the low damage content for both picking rate and picking quality were 7.8 per cent and 18.6 per cent respectively.[38]

These findings seem to indicate that an operator spends less time looking for defectives when more defectives are presented to him. Thus, he has more time available to pick, and is able to increase his net picking rate proportionately.

Previous Research at Georgia Institute of Technology

Overall Project.--In 1950, a project was begun under the auspices of the Engineering Experiment Station, Georgia Institute of Technology and the Agricultural Experiment Station of the University of Georgia. This project directed by J. J. Moder and N. M. Penny was completed, and a report, Industrial Engineering and Economic Studies of Peanut Marketing, was published in December, 1954.[39]

The above report has formed the basis for further research by Calhoun and Zimmer.[40] [41] This present thesis is a continuation of the work begun by Calhoun, although certain portions are based upon the work of Zimmer.

Calhoun's Work.--In order to explore the subject of hand quality picking of small objects, it was necessary first to develop a criteria and an independent measure of this criteria. Furthermore, this criteria had to be analyzed statistically in order to establish the true sources of variance.

Calhoun assumed the following factors were the most important ones involved in hand quality picking:[42]

1. Operator
2. Method
3. Position
4. Belt speed
5. Belt loading
6. Damage-Density
7. Replication

As the measure of his criteria Calhoun used the operator's total number of pickouts per minute and the per cent of good objects placed in the pickouts (picking errors).[43] Other factors such as illumination, work-surface height, etc., were considered, but they were felt to be of relatively minor importance.[44] He investigated his criteria through the use of a factorially designed experiment.[45]

Calhoun concluded that:[46]

1. The operators he used had significantly different picking rates.
2. Operators differed significantly in their picking errors.
3. Lower belt-loadings resulted in higher picking rates and better quality than did higher belt loadings.
4. The "pick and throw" method was superior to the "roll" method.
5. An increase in belt speed adversely affected the number of picking errors.
6. All of the variables investigated had an effect upon both the picking rate and the number of picking errors made.

His conclusions were subject to the following limitations:[47]

1. Only four operators were used. They were not selected at random and were women with many years experience at picking.
2. Only two belt speeds were used.
3. A belt loading of 33.3 per cent density was the lowest investigated.

Calhoun recommended that any further study of hand quality picking be directed toward:[48]

1. The use of a larger number of operators selected at random.
2. Using lower belt loadings.

3. Belt speeds higher and lower than those which he used.

4. Lower damage-density levels.

Zimmer's Work.--Zimmer saw the need for further study of the factors which Calhoun found to be statistically significant. In particular he was interested in the differences between operators and the determination of an optimum density-belt speed combination for a given rate of flow.[49]

Zimmer studied the operation of hand quality picking in detail. From his investigation he determined aptitude characteristics which the job required. He therefore selected a battery of tests which he assumed would be predictors of job success in hand quality picking. The tests he used were:[50]

1. The Purdue Pegboard; Right Hand Test, Left Hand Test, Both Hands Test, and the Right plus Left plus Both Hands for manual dexterity.

2. The Purdue Pegboard Assembly Test for finger dexterity.

3. The Moore Eye-Hand Coordination and Color Matching Test for aiming.

4. The Bausch and Lomb Visual Classification and Placement Test for visual skills.

Following Calhoun's recommendations concerning belt loading and belt speed, Zimmer chose several combinations of belt density and belt speed to give a constant rate of flow.[51] He used densities both above and below those recommended by Calhoun. He did the same with the belt speed. The rate of flow was fixed at a level which would keep the operator continuously supplied with defectives for picking.

Zimmer set forth the following objectives:[52]

1. To select tests which discriminate between the aptitude characteristics of successful and unsuccessful hand quality pickers.

2. To determine an index of correlation between the scores on the test employed and the operators' picking rates.

3. To develop density-belt speed combinations which result in optimum pickout rates and high quality of pickouts for:

    a. A constant rate of flow of objects.

    b. Damage content.

    c. Operators grouped into classes according to their scores on selected aptitude tests.

Zimmer's conclusions were as follows:[53]

1. The test battery which he had selected did discriminate between operators whose aptitude scores fell in the upper quartile and those whose scores fell in the middle two quartiles.

2. He determined an "index of correlation" between the scores on the entire test battery and the operators' picking rate of .877. This figure is significant at the .001 probability level of linear correlation coefficients.

3. With reference to his final objective, he drew the following conclusions:

    a. A density of 22 per cent and a belt speed of 46 feet per minute resulted in optimum picking rates of defective objects and a high picking quality for all operators.

    b. The picking rate dropped at belt speeds below and densities above their optimum values.

c. The picking quality dropped at belt speeds above and densities below their optimum values.

4. He also found from his results that the high damage content consistently resulted in higher picking rates of defective objects and better picking quality than the low damage contents.

Summary.--In this chapter, the manual quality picking operation and the means of measuring it were described. Those factors which influence manual quality picking of small objects were discussed. Previous research was reviewed since the results and limitations of these earlier studies form the basis for this present investigation.

CHAPTER III

OBJECTIVE

The purpose of this investigation is to study the effects of:

1. Operators
2. Method
3. Position

upon the net picking rate and the picking quality rate in the manual quality picking of small objects. Two further purposes of this study are to verify the use of psychological aptitude tests to predict operator success in hand quality picking and to investigate the relationship of an operator's performance to his dominant hand.

The specific objectives of this thesis are as follows:

1. To determine if the picking method affected the net picking rate when other factors were at optimum levels.

2. To determine if the picking position affected the net picking rate when other factors were at optimum levels.

3. To determine if there was any relationship between an operator's performance and his dominant hand.

4. To validate the use of certain aptitude tests to predict job success in manual quality picking.

For assurance that the results sought for the above objectives are not pure chance variations of individual performance, the following null hypotheses are to be tested at various probability levels which are set forth in Chapter VI:

1. There is no significant difference between operator net picking rates and picking quality rates due to operator differences.

2. There is no significant difference in the net picking rates due to using different picking methods.

3. Operator net picking rates and picking quality rates do not differ significantly from one position to another.

4. Left-handed operators pick equally as well as right-handed operators at all picking positions.

5. Operators' average net picking rates bear no significant relationship to the operators' scores on the selected aptitude tests.

A factorial mixed model experiment is to be employed to test the above hypotheses.

CHAPTER IV

EXPERIMENTAL DESIGN

This chapter consists of a brief description of the experimental subjects and the manner of their selection. Also described are the experimental apparatus and objects used for the control of the factors under investigation.

Subjects.--Nine white male experimental operators were used in this investigation. Their ages ranged from 20 to 23 years. The group contained four left-handed and five right-handed individuals. The subjects were not skilled in manual quality picking of small objects. These nine persons were selected at random from three strata (see below Basis of Selection) of a population of 44 students studying Motion and Time Study under the direction of Dr. R. N. Lehrer, Georgia Institute of Technology, Atlanta, Georgia. This course is part of the required curriculum for Industrial Engineering students and is usually taken during the Junior year.

Basis of Selection.--The method of selecting the operators was based on the results of Zimmer's investigation.[54] The entire class was given the Purdue Pegboard Test for manual and finger dexterity.[55] The histogram of their total raw scores on the four pegboard tests is given in Figure 13, Appendix I. This distribution was divided into three strata as shown on Figure 13, from which the operators were drawn. Since the distribution of scores did not follow a normal pattern, the median score of 92.0 was selected as the best measure of central tendency for the group. The modal and mean scores are shown on Figure 13. In addition to the peg-board test the selected subjects had to meet the minimum visual requirements for inspection and machine work recommended by the Bausch & Lomb Optical Company.[56]

Apparatus.--The apparatus used in this investigation was essentially the same as that designed and constructed by Calhoun.[57] He built a special picking table consisting of the following components: the frame, the belt carrier, the hopper and feed control, and the drive.

Frame: This component which supports the other parts of the apparatus was constructed of galvanized iron pipe.

Belt Carrier: This consisted of side rails, cross supports, platform, pulleys and an endless conveyor belt. Mounted at one end of the belt carrier were the hopper and feed control and the drive.

Hopper and Feed Control: The hopper was constructed of galvanized iron sheets supported by an angle iron framework. The feed control was located on the outside lower edge of the hopper. It consisted of a 12" brush and a movable aluminum gate which could be raised or lowered in order to regulate the relative belt density.

Drive: This was located to the rear of the hopper and at the extreme end of the belt carrier. Power was provided by a 1750 r.p.m. 115 v., 1/2 HP electric motor transmitted through variable speed hydraulic drive.

Some modifications of the hopper and the drive were found desirable for this investigation. The flow of objects from the hopper was somewhat dependent upon the number of objects in the hopper. In other words, when the hopper was full, the pressure upon the conveyor was greater and more objects flowed under the regulating gate than when the hopper was nearly empty. This condition was corrected through the addition of a baffle, Figure 1, placed horizontally in the neck of the hopper. This baffle was wide enough to support most of the objects, yet narrow enough to allow an unobstructed flow of material to the belt.

Previous experimenters had used a variable speed hydraulic transmission to drive the picking table conveyor. It was observed that due to changes in oil temperature and conveyor drag, the drive was continuously changing speed. This condition was remedied through the substitution of a mechanical transmission, Figure 2, consisting of a series of pulleys and V-belts.

Objects.--Great Northern beans were used as the objects in this investigation. These beans are representative of many edible products that are hand-quality picked, such as peanuts, pecans, and coffee beans. Because of their hardness, shape, and resistance to wear and decay, these beans were decided upon for this study.

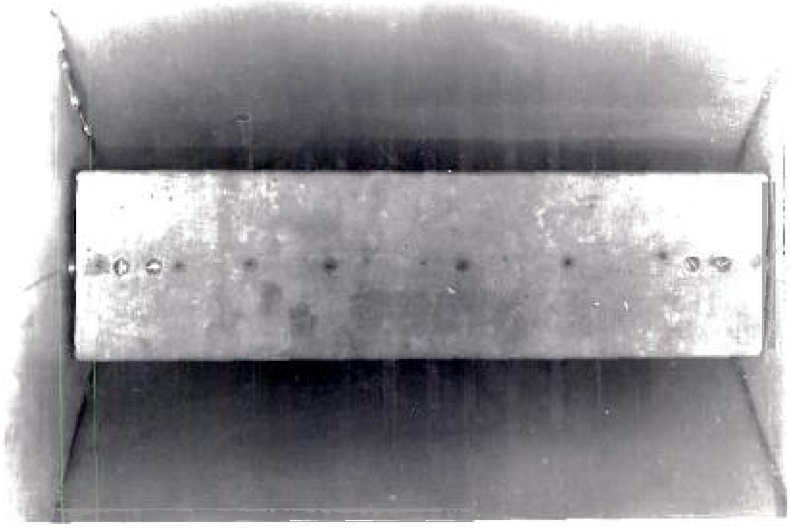

Figure 1. Baffle Feed Control for the Picking Apparatus

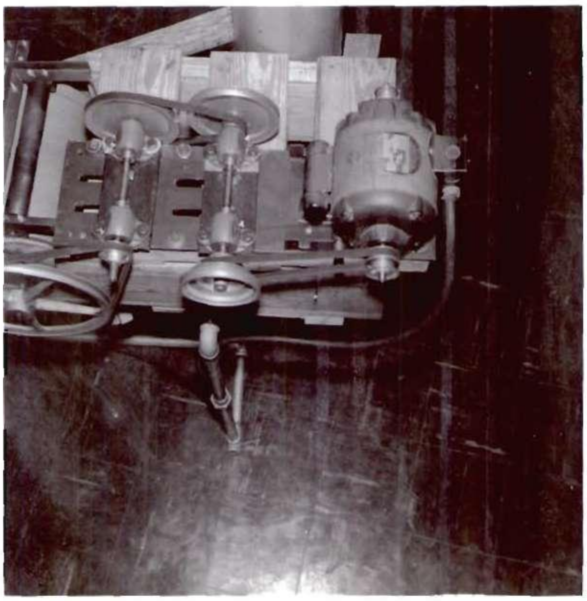

Figure 2. The Apparatus Drive

Pinto beans were used to represent the damaged objects. Pinto beans are very similar to Great Northern beans. They differ largely in their color. Whereas the Great Northern beans are solid white, Pinto beans are speckled brown.

The Pinto beans were mixed with the Great Northern beans to form a lot with a 4 per cent (by weight) damage content.

CHAPTER V

EXPERIMENTAL PROCEDURE

This chapter outlines the factors studied and the levels of each variable. The overall experimental conditions are discussed, together with the experimental plan and operator time table.

Variable Factors.--The following variables were investigated at the indicated levels:

1. Operator - Nine
2. Method - Three

   Method 1. The "roll" method
   Method 2. The "pick and throw - multiple object" method
   Method 3. The "pick and throw - single object" method

3. Position - Three

   Position 1. Operator at right side of belt with belt moving from the operator's left to his right, Fig. 3.
   Position 2. Operator at left side of belt with belt moving from the operator's right to his left, Fig. 4.
   Position 3. Operator at end of belt with belt moving toward the operator, Fig.5.

4. Replication - Two

   The complete experiment was run twice. However, each replication is analysed separately in order to remove the variance due to the operator's practice between replications.

Constant Factors.--The following factors were held constant at the indicated level:

Figure 3. "Right" Side Picking Position

Figure 4. "Left" Side Picking Position

Figure 5. "End" Picking Position

1. Rate of Flow - 8.3 pounds of beans per minute.
2. Belt Speed - 43.2 feet per minute. This was the observed speed of the belt while running without load.
3. Belt Density - 25 per cent.
4. Damage Content - 4 per cent.
5. Illumination - 75 foot-candles.
6. Work-Surface Height - 41.5 inches. This was measured from the floor to the top of the pick-out tray. This height was below the elbow of any operator.
7. Operator Posture - Standing.
8. Operator Pace - Brisk; i.e., a pace of performance beyond which fumbling occurs.

Overall Conditions.--The experiments were conducted in the School of Industrial Engineering Laboratory, Georgia Institute of Technology. The experimental data was gathered over the period June 1st to June 9th, 1955, and during the hours between 8:00 a.m. and 4:00 p.m.

The laboratory, where the apparatus was located, was well ventilated and adequately lighted. Temperature and humidity levels were comfortable throughout the experiments. In addition to the normal lighting within the room, a supplementary light fixture was suspended five feet above the picking conveyor, providing an overall illumination of 75 foot-candles at the working surface.

Experimental Plan.--Because of the few operators used and the limited time available, it was felt that more meaningful data would result from a non-randomized experimental plan. Only the subjects were selected at random. All other factors in the experiment are either variables at fixed levels or constants.

The sequence of runs was organized as a Latin Square. Since there were three methods and three positions, nine method-position combinations were employed. Using these nine combinations, it was decided to balance operators against orders. From this Latin Square design, a sequence of runs was set up in which a different combination was used during the nine runs made by each operator during each replication. Furthermore, the combinations were arranged in a different sequence for each order. The same process was repeated for the two replications. From Table 8, Appendix I, it can be seen that no two runs are alike with respect to their location in the table. Thus, each method-position combination appeared once and only once in each sequence location of the nine runs performed by each operator.

The subjects were not paid for their participation. However, they were rewarded with some time off from their Motion and Time Study laboratory at the end of the term. All the subjects appeared to be amply motivated and exhibited considerable interest in the conduct and outcome of the experiments. In addition to the nine subjects selected, nine assistants were obtained from the same class. These individuals were used in order to keep the subjects from doing any work other than actively picking or waiting between runs.

The conduct of an experiment for one operator is described below:

The operators had previously been acquainted with the purpose of the investigation. The methods and positions to be used were described and demonstrated. The operator was then shown the nine combinations of methods and positions with which he would pick, and the sequence in which they would be performed. He was then put through a nine minute learning session during which he picked one minute at each combination and in the exact order of the record runs. At the end of this preliminary experiment the subject was encouraged to ask questions on anything which was not clear to him.

The record runs were three minutes long. At the word "start" the conveyor was started and the operator began picking. Time was kept using a decimal minute stop watch. At the end of the run the signal "stop" was given; the operator ceased picking and the conveyor was halted. The receptacle containing the pickouts was then removed from the conveyor apron and dumped on the counting table.

Before the counting began the hopper was refilled by the helper. The next run was then started in the same manner as described above. While this subsequent run was under way, the assistant proceeded to count and record the number of defectives and the number of good objects placed in the pickouts. After being individually counted the pickouts were thoroughly mixed with the original lot. Any reduction in the total damage content due to this procedure was considered to be negligible.

The total elapsed time between runs varied from one to two minutes. During the time between runs, the operators remained standing.

Operator Schedule.--When the operators could work was largely determined by their class schedules. The only requirement imposed was that no operator was allowed to perform both replications on the same day. The schedule of experimentation was as follows:

	First Replication		Second Replication	
Operator	Date	Hour	Date	Hour
1	June 1	1:00 pm	June 3	2:00 pm
2	June 8	1:00 pm	June 9	1:00 pm
3	June 1	3:00 pm	June 2	3:00 pm
4	June 2	11:00 am	June 3	11:00 am
5	June 2	12:00 pm	June 3	3:00 pm
6	June 2	1:00 pm	June 6	2:00 pm
7	June 2	2:00 pm	June 6	8:00 am
8	June 8	11:00 am	June 9	9:00 am
9	June 6	11:00 am	June 7	11:00 am

Summary.--Each of the variables tested and those factors which were standardized for this investigation has been set forth. The overall conditions, experimental plan, and the operator schedule have been discussed at length. In short, this chapter has been an effort to provide complete information regarding the experimental procedure.

CHAPTER VI

ANALYSIS OF RESULTS

This chapter is divided into four major sections. The first section deals with the methods of analysis and the assumptions which underlie the analysis.

The second and third sections are concerned with a statistical analysis of the net picking rate and the picking quality rate respectively. The final section is concerned with the relationship between the operators' performance and certain aptitude characteristics.

It is desired in this chapter to provide the reader with a clear-cut and easily-understood analysis without sacrificing necessary technical details. That data which, although informative, is not wholly necessary to the analysis, is relegated to the Appendix.

In discussing each independent variable, the statistical analysis is broken down according to the two dependent variables which were measured; i.e., the net picking rate and the picking quality rate. The net picking rate primarily determines the economy of hand quality picking of small objects. However, the picking quality rate is an important consideration in the economy of hand quality picking. The analysis of variance was the statistical technique utilized in testing all data.[58]

Quotidian Effect.--An underlying assumption for the test of significance in the analysis of variance is that the experimental error variance is from populations whose variances are homogeneous.

In order to satisfy this assumption, each replication was analyzed separately, and no attempt was made to pool the data of the two replications. It was felt from the beginning that there was no justification in assuming that those factors which might be significant in the first replication would necessarily be significant in the second. It was believed that the quotidian effect on the part of these unskilled operators would be so great that no conclusions should be made beforehand regarding the effect of a factor between replications. This reasoning is borne out by Figures 6 and 7 which show the average net picking rate for each replication classified according to operators and experimental order, respectively. An analysis of these Figures shows a considerable increase in operator performance between the first and second replication. Also the curves show that the last experimental order for each replication was higher than any other order in the replication which indicates that a performance increase took place within each replication. It is evident from these curves that a necessary requirement of any experiment of this type is that no experimental condition should appear more than once in the final order. Otherwise that condition which occurred most frequently in the last order would be unduly favored.

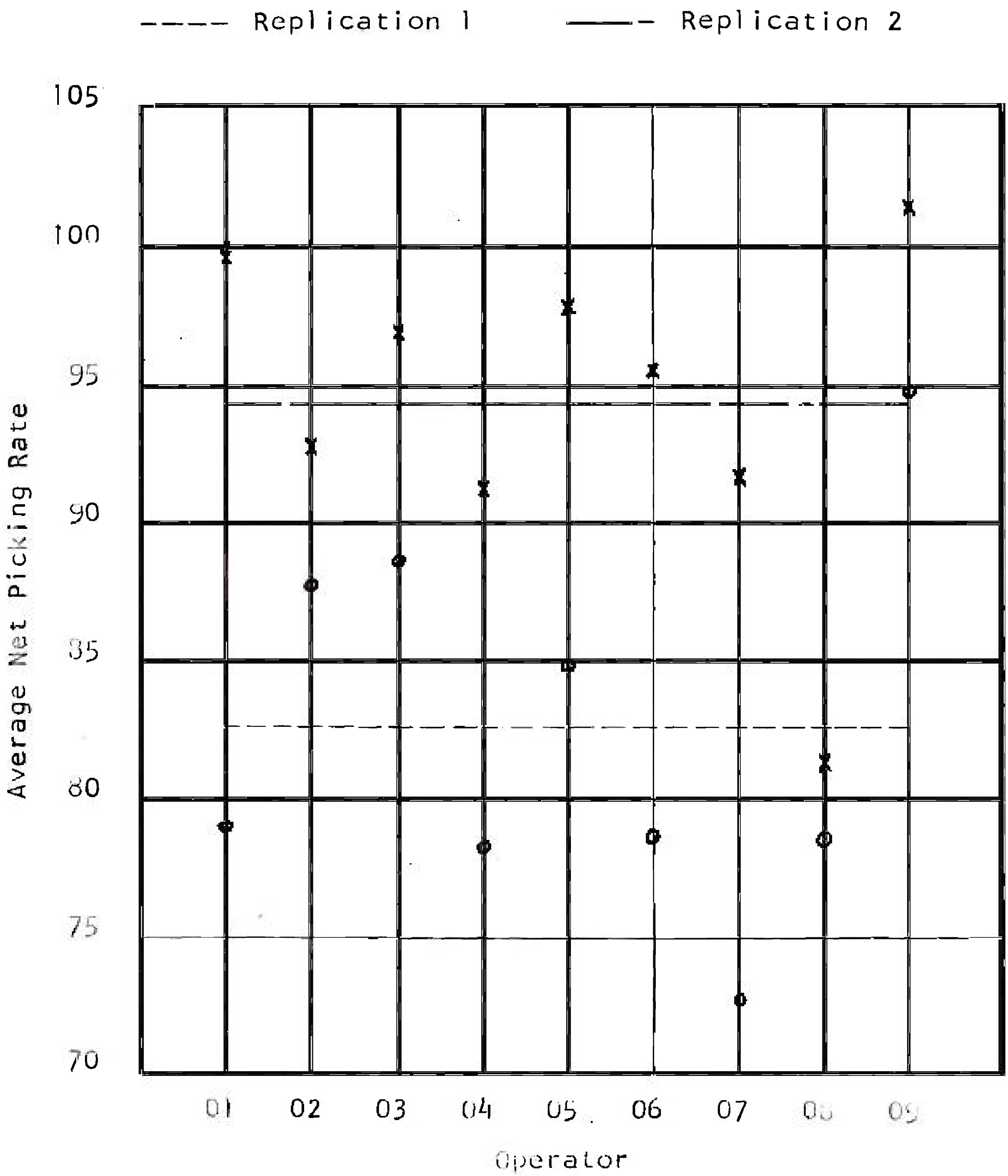

Figure 6. Average Net Picking Rate per Replication Versus Operator

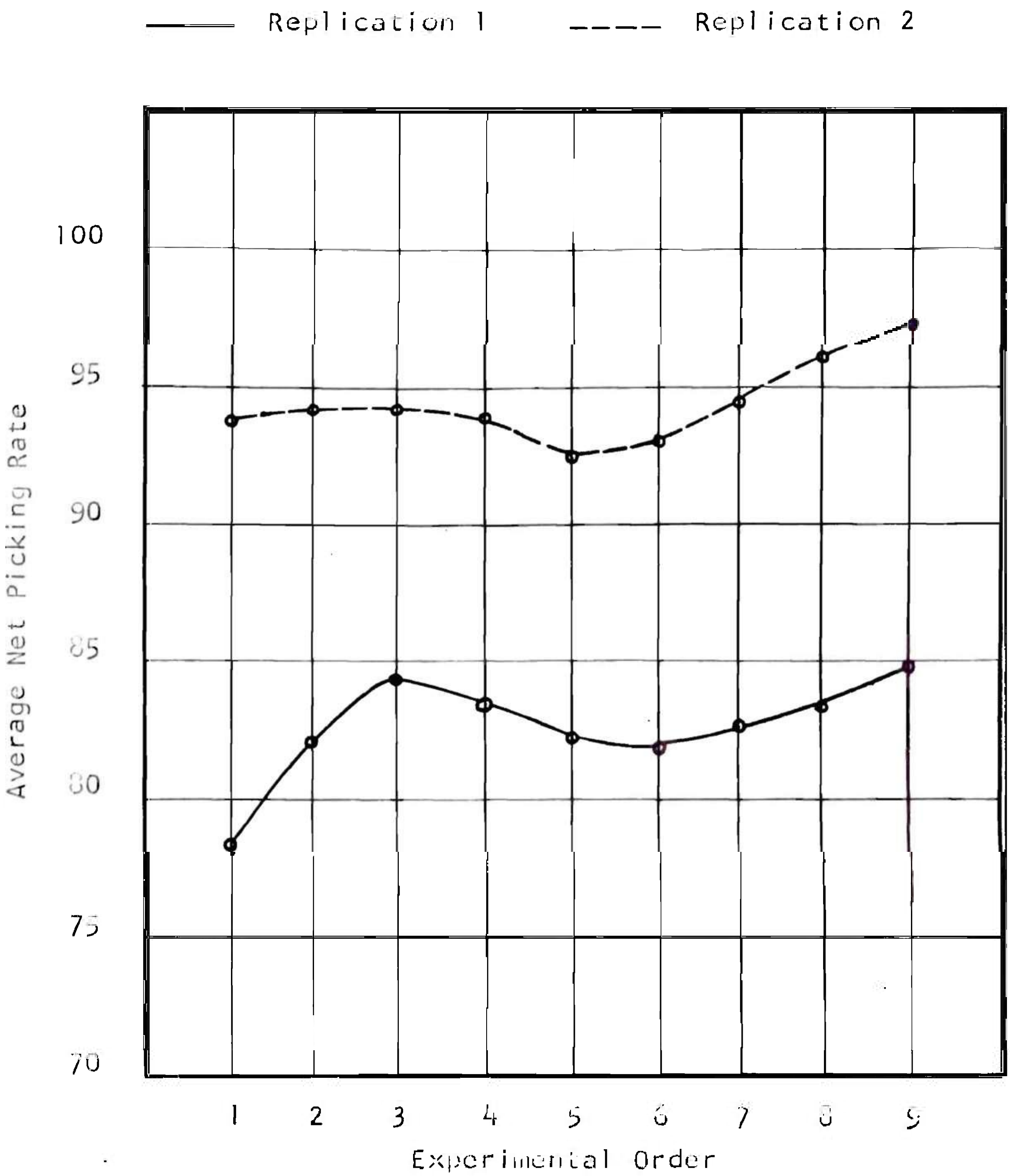

Figure 7. Average Net Picking Rate per Replication Versus Experimental Order

This evidence lends weight to the desirability of a non-random pattern for the experimental orders whenever the experimenter is unable to have his subjects reach a plateau of their individual learning curves before the collection of experimental data.

The independent variables in the experiment were classified as Model I and Model II variables according to their effect upon the dependent variables.[59] The Model I variables, methods and positions, have fixed levels. The Model II variables, the operators, were selected at random from three strata of a population of operators. (See above p. 18). Model II or random variables allow inference to be made about the entire population of operators whereas for Model I variables inference can be made only to the particular levels studied.

The model equation for the experiment, analysis of variance table, components of variance table, sample calculations and results of the analysis of variance are given in Appendix II.

Statistical Analysis of the Net Picking Rate

Those factors which affect the net picking rate significantly are given in Table 1. The complete table of mean squares is given in Appendix II.

Tests of significance were made at three levels of probability, as indicated on the table by asterisks. However, only the .01 and .001 levels were considered for accepting or rejecting a hypothesis. A complete discussion of testing the

Table 1. Significant Factors affecting the Net Picking Rate.

Factor	Degrees of Freedom	Mean Square Replication 1	Mean Square Replication 2
Operator	8	430 ***	340 ***
Method			
"Pick & Throw" vs. "Roll"	1	460 **	420 **
Position			
Right vs. Left	1	-	125 *
Operator x Method	16	53 *	54 *
Residual	32	21	22

\- Not significant
* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

mean square of each variable is given in Appendix II.

Table 2 expresses the significant main effects and interactions as a per cent of the grand average for all operators of the net picking rate. The grand averages were 82.6 and 94.4 net pickouts per minute for Replications 1 and 2 respectively. These averages were tested for a significant difference by the Student t-Test utilizing the residual variance of each replication. The difference proved to be statistically significant at the .001 level of probability.

The discussion below is in terms of a per cent of the grand average. Both main effects and interactions are discussed in the order of decreasing importance.

Operator.--This investigation, as have many others utilizing human beings, points out that the difference between individuals can have a great effect upon the experimental results, and often contributes the largest amount of variance to the experiment.

In this study, the difference between operators was significant in both replications at the .001 probability level. Thus the hypothesis that there is no significant difference between operator net picking rates due to operator difference is rejected. Table 2 indicates the relative rank of each operator. It also shows a difference of 26.6 and 21.6 per cent of the grand average net picking rate between the highest and the lowest operators for Replications 1 and 2 respectively.

Table 2. Significant Main Effects and Interactions Expressed as a Per Cent of the Grand Average for all Operators of the Net Picking Rate

Replication 1							
Operator	Operator Score	Method 1	Method 2	Method 3	Position 1	Position 2	Position 3
1	95.72	84.70	98.55	103.93	-	-	-
2	106.30	99.09	107.69	112.13	-	-	-
3	107.19	111.19	108.90	83.89	-	-	-
4	94.55	88.86	100.84	93.98	-	-	-
5	102.77	100.56	106.35	101.36	-	-	-
6	95.06	91.29	94.80	99.09	-	-	-
7	88.15	88.46	88.20	87.79	-	-	-
8	95.23	90.74	91.30	85.78	-	-	-
9	114.82	89.56	117.64	118.45	-	-	-
Average	100.00	93.83	101.59	98.49	-	-	-

Grand average of all operators: Replication 1 = 82.63 net pickouts per minute

\- Indicates factor was not significant

Table 2. Significant Main Effects and Interactions Expressed as a Per Cent of the Grand Average for All Operators of the Net Picking Rate (continued)

Replication 2							
Operator	Operator Score	Method			Position		
		1	2	3	1	2	3
1	106.68	100.02	107.19	112.84	-	-	-
2	98.32	94.48	98.84	101.66	-	-	-
3	102.65	106.96	103.78	91.78	-	-	-
4	96.56	92.60	100.61	92.96	-	-	-
5	103.58	99.08	108.00	103.67	-	-	-
6	101.04	90.96	102.49	103.56	-	-	-
7	97.08	98.72	96.96	95.54	-	-	-
8	86.05	81.43	88.13	88.60	-	-	-
9	107.67	104.26	112.37	106.37	-	-	-
Average	100.00	96.50	102.04	99.66	97.88	101.22	100.77

Grand average of all operators: Replication 2 = 94.39 net pickouts per minute

- Indicates factor was not significant

This difference serves to substantiate the earlier findings of Calhoun and Zimmer. However, it should be pointed out the general level of performance of all operators increased 11.76 per cent between replications; and although the highest operator was the same person in both replications, the lowest operators were different people in Replications 1 and 2. This is evidence that the quotidian effect between replications could cause erroneous conclusions regarding the validity of predictors if the results of both replications were pooled and averaged.

Method.--This variable had considerable effect on the net picking rate. The variance attributable to the difference in methods was broken down by individual degrees of freedom using the system outlined by Cochran and Cox.[60] This breakdown shows that the difference between the "pick and throw" methods, and the "roll" method, was significant at the .01 probability level. Thus the hypothesis that there is no significant difference in the operator net picking rate due to using different picking methods is rejected. The hypothesis is rejected with equal confidence for both replications.

The "pick and throw" methods resulted in a 6.2 per cent and 4.3 per cent higher net picking rate than the "roll" method for Replications 1 and 2 respectively. The difference between the two "pick and throw" methods, which was found not to be significant, amounted to 3.1 and 2.4 per cent for Replications 1 and 2 respectively.

The reason for the inferiority of the "roll" method seems to lie in the indecision of the operator as to retaining a good object in his hand. This reasoning is substantiated by data which shows the "roll" method to have a slightly better picking quality rate.

Picking Position.--This variable was found to have some effect on the net picking rate. The sums of squares attributable to the difference in positions was broken down in the same manner as discussed above for the difference in methods. This breakdown compares the two side positions with the end position, and compares the right side with the left side. The results show that there was no significant difference between positions at the .01 probability level. Thus, there was not sufficient evidence to reject the hypothesis that the operator net picking rates do not differ significantly from one position to another.

Operator x Method.--Six out of nine operators did better in the first replication using the "pick and throw" methods, whereas seven out of nine did better in the second replication using the "pick and throw" methods. However, the amount of improvement varied considerably from one operator to another and between replications. This interaction indicates primarily a variation from operator to operator in the difference in picking rates for the "pick and throw" methods as opposed to the "roll" method.

Statistical Analysis of the Picking Quality Rate

Those factors which significantly affect the picking quality rate are given in Table 3. The complete table of mean squares is given in Appendix II.

Tests of significance were made at three levels of probability, as indicated on the Table by asterisks. However, only the .01 and .001 levels were considered for the acceptance or rejection of a hypothesis. A complete discussion of testing the mean squares of each variable is given in Appendix II.

Table 4 expresses the significant main effects and interactions as a per cent of the grand average for all operators of the picking quality rate. The grand averages were 5.4 and 5.0 good objects picked per minute for Replications 1 and 2 respectively. These averages were tested for a significant difference by the Student t-Test utilizing the residual variance of each replication. The difference was not statistically significant at the .05 level of probability.

The discussion below is in terms of a per cent of the grand average. Both main effects and interactions are discussed in the order of decreasing importance. It might be well at this time to re-emphasize that a low picking quality rate is better than a high picking quality rate.

<u>Operators</u>.--The variance between operators proved to be significant at the .001 probability level for both replications.

Table 3. Significant Factors affecting the Picking Quality Rate

Factor	Degrees of Freedom	Mean Square Replication 1	Mean Square Replication 2
Operator	8	66.3 ***	136.3 ***
Method	2	-	19.5 **
Operator x Position	16	17.7 **	-
Residual	32	6.5	4.3

- Not significant
* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

Table 4. Significant Main Effects and Interactions Expressed as a Per Cent of the Grand Average for all Operators of the Picking Quality Rate

Replication 1							
Operator	Operator Score	Method 1	Method 2	Method 3	Position 1	Position 2	Position 3
1	70.3	-	-	-	57.4	49.4	103.0
2	31.5	-	-	-	39.5	29.0	26.5
3	120.3	-	-	-	108.6	144.4	111.1
4	159.1	-	-	-	113.5	174.6	188.8
5	149.9	-	-	-	158.6	138.2	151.8
6	103.6	-	-	-	88.9	125.3	96.9
7	157.3	-	-	-	288.1	107.4	76.5
8	42.6	-	-	-	30.9	53.7	45.7
9	59.4	-	-	-	43.2	64.2	76.5
Average	100.0	-	-	-	-	-	-

Grand average of all operators: Replication 1= 5.4 good objects picked per minute

- Indicates factor was not significant

Table 4. Significant Main Effects and Interactions Expressed as a Per Cent of the Grand Average for all Operators of the Picking Quality Rate (Continued)

Replication 2							
Operator	Operator Score	Method 1	Method 2	Method 3	Position 1	Position 2	Position 3
1	70.0	-	-	-	-	-	-
2	20.0	-	-	-	-	-	-
3	198.0	-	-	-	-	-	-
4	228.0	-	-	-	-	-	-
5	162.0	-	-	-	-	-	-
6	74.0	-	-	-	-	-	-
7	24.0	-	-	-	-	-	-
8	30.0	-	-	-	-	-	-
9	86.0	-	-	-	-	-	-
Average	100.0	80.5	105.2	113.1	-	-	-

Grand average of all operators: Replication 2 = 5.0 good objects picked per minute

- Indicates factor was not significant

The hypothesis concerning operator difference as it pertains to the picking quality rate is rejected. Table 4 indicates the relative rank of each operator. It shows a difference of 127.6 and 208.0 per cent of the grand average picking quality rate between the best and the poorest operator for Replications 1 and 2 respectively.

This wide disparity, which also has been found by previous experimenters, may be attributed to the individual's ability or lack of same to direct his utmost attention, zeal, and manual skills to the job at hand. Although most operators improved between replications, some of the operators did considerably worse. This was probably due to an attempt to increase their gross picking rate during the second replication.

Method.--The difference between methods was found to be significant at the .01 probability level for the second replication only.

Thus the hypothesis that there is no significant difference in the operator picking quality rate due to using different picking methods is rejected. There is statistical evidence present for rejecting the hypothesis only in the second replication.

Table 4 shows that, insofar as the picking quality rate is concerned, Method 1 (Roll) is superior to either Method 2 or 3 (Pick and Throw).

It is obvious that one of the causes for the lower net picking rate of Method 1 is the better quality resulting when this method is used. Table 4 also shows that Method 3, which is the "pick and throw (single object)" method, resulted in the poorest picking quality rate.

Picking Position.--There was no significant difference between picking positions in either replication. However, Position 1, the right-side position, gave a poorer result than did either Position 2 or 3.

Operator and Position.--This interaction proved to be significant at the .01 probability level for the first replication only. This difference is probably due to the operator's reaction to changing from one position to another during the experiment. However, this does not explain why the interaction did not affect the net picking rate. It is felt the variance due to this interaction is the result of unfamiliarity with the operation more than anything else.

Statistical Analysis of Operator Hand Dominance and Operator Aptitude Test Scores.

This discussion is separate from the preceding analysis because it deals with two hypotheses which were of a secondary nature to this investigation. The results obtained should be of interest to some investigators.

Operator Hand Dominance.--It was felt from the beginning of this study that it would be interesting to see if an operator's picking rate was affected by his being left-handed or right-handed.

The hypothesis was made that left-handed operators pick as well as right-handed operators at all picking positions. The nine experimental subjects were divided nearly equally; five were right-handed and four were left-handed. In order to test the above hypothesis, the operator net picking rates were summed over all three positions for both replications for both groups.

In order to test for a statistical difference between the two groups, it was decided to use the Student t-Test at the .05 probability level.[61]

Table 5 shows the application of the Student t-Test to the experimental data arranged according to the operator's dominant hand. There was not sufficient evidence at the .05 probability level to reject the hypothesis.

Operator Aptitude Test Scores.--The relationship of an operator's manual aptitude and his picking performance was brought up by Calhoun and thoroughly investigated by Zimmer.[62] [63] It was felt from the start of this investigation that since considerable data of a similar nature was being gathered that an effort should be made to validate Zimmer's conclusions.[64] Therefore, the following null hypothesis was set forth: The operators' average net picking rates bear no significant relationship to the operators' scores on the selected aptitude tests.

Table 6 and Figure 8 show the operators' average net picking rate (for the two "pick and throw" methods summed over both replications) as compared with their total raw score

Table 5. Student T-Test of the Left-Handed Operators Compared with the Right-Handed Operators.

Left-Handed Operators				Right-Handed Operators			
No.	Picking Rate	X_i	X_i^2	No.	Picking Rate	X_i	X_i^2
03	91	1	1	01	94	4	16
06	92	2	4	02	93	3	9
07	82	-8	64	04	87	-3	9
09	101	11	121	05	93	3	9
				08	82	-8	64
TOTAL		6	190			-1	107

$n_L = 4 \qquad X_o = 90$

$$\bar{X}_L = X_o + \frac{\Sigma X_i}{n_L}$$

$\bar{X}_L = 91.5$

$n_R = 5 \qquad X_o = 90$

$$\bar{X}_R = X_o + \frac{\Sigma X_i}{n_R}$$

$\bar{X}_R = 89.8$

Table 5. Student T-Test of the Left-Handed Operators Compared with the Right-Handed Operators (Continued)

$$\sigma^2 = \frac{(\Sigma X_L^2 - (\Sigma X_L)^2/n_L) + (\Sigma X_R^2 - (\Sigma X_R)^2/n_R)}{(n_L + n_R - 2)} = 41.1$$

$$\sigma = 6.42$$

$$t_x = \frac{\overline{X}_L - \overline{X}_R}{\sigma} \sqrt{\frac{n_L \times n_R}{n_L + n_R}} = 0.395$$

Tabular value of t = 2.37*

t_x is less than 2.37 and therefore non-significant

* .05 probability level and seven degrees of freedom

on the Purdue Pegboard Test. The correlation coefficient was calculated using the Spearman Rank Method and was tested against a table of linear correlation coefficients at the .05 probability level.

As seen from Table 6, there is no significant correlation existing between the two variables. Therefore, the above hypothesis is accepted. Thus for this group of subjects there was no significant correlation between their net picking rates and their aptitude test scores. Some evidence still exists which indicates that aptitude tests may predict the more successful operators. This investigation does point out that no all-encompassing conclusions can be drawn concerning the validity of job predictors from one or two relatively small samples.

<u>Summary.</u>--A detailed analysis of the experimental results was given in this chapter. The observed quotidian effect of the experimental subjects was discussed.

The hypotheses set forth in Chapter III were discussed and tested for significance. These hypotheses were either accepted or rejected and the reasons for the decisions were discussed.

By means of statistical and tabular analysis of the results an optimum picking method and position were selected. Also the effect which each independent variable had upon the net picking rate and the picking quality rate was determined and discussed.

Table 6. Rank Comparison of the Operator's Average Net Picking Rate with Their Score on the Purdue Pegboard Test

Operator No.	Average Net Picking Rate Ty	Total Raw Score on Test Tx	Rank of x	Rank of y	Difference di	(Difference)^2 di^2
1	94	93	6	2	4	16
2	93	101	4	3.5	.5	.25
3	91	107	1	6	-5	25
4	87	104	3	7	-4	16
5	93	95	5	3.5	1.5	2.25
6	92	86	9	5	4	16
7	82	90	7	9	-2	4
8	82	87	8	8	0	0
9	101	105	2	1	1	1
				Total	0	80.5

<u>Calculation of Correlation Coefficient</u>

$$R(\text{rho}) = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$$

$$= 1 - \frac{6(80.5)}{9(81-1)}$$

$$R = .33$$

Tabular value of r for 8 degrees of freedom at the .05 probability level is .632

R is less than .632; therefore, there is no evidence of a significant correlation

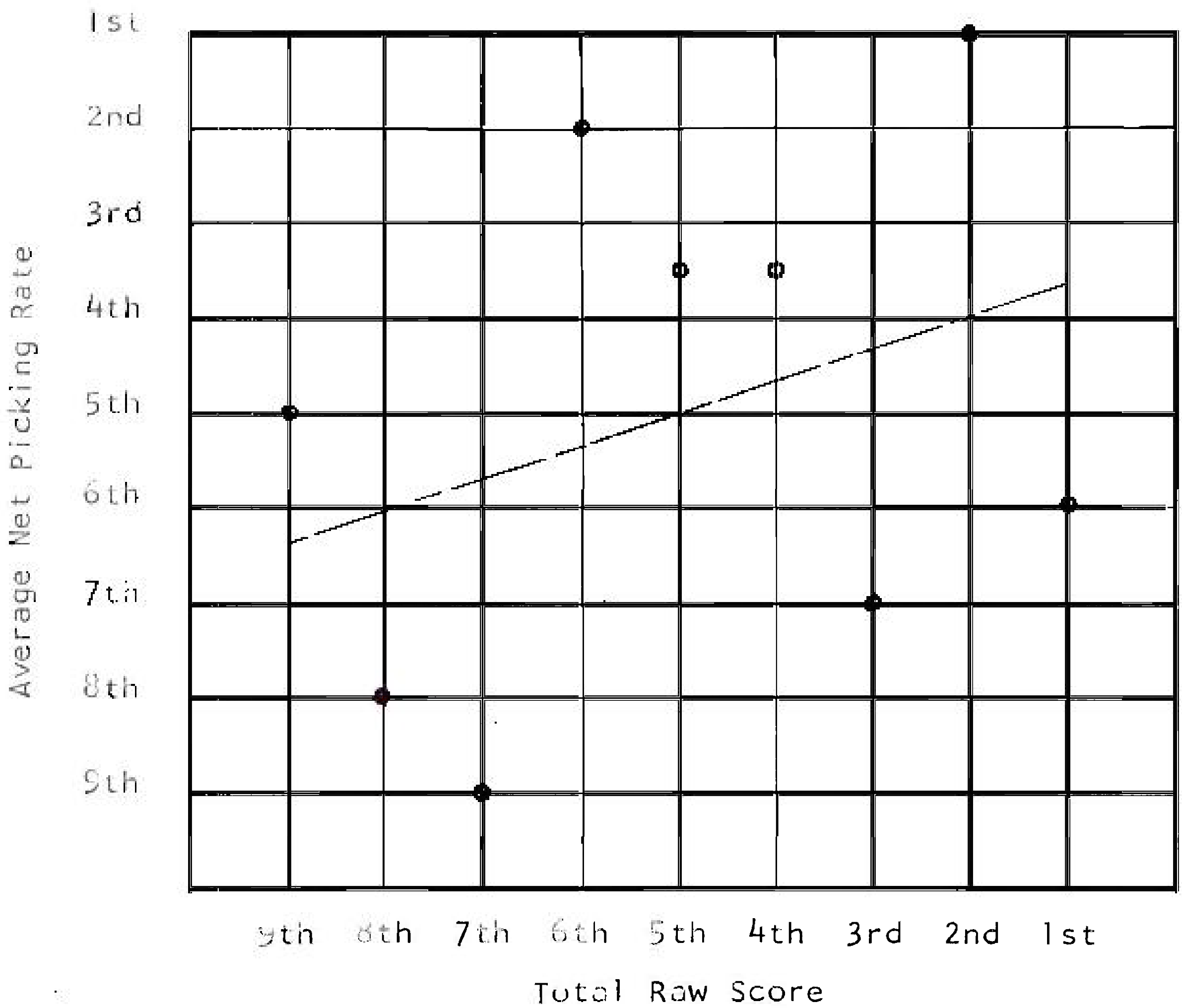

Figure 8. Average Net Picking Rate per Operator Versus Total Raw Score on the Purdue Pegboard Tests

In the next chapter the limitations and conclusions of this investigation are summarized. Recommendations are made for further investigation of problems which arose during this study, and which go beyond the scope of this thesis.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations discussed below are based solely upon the experimental results of this investigation and are subject to the following limitations:

1. The experimental subjects were:

    a. Male college students rather than middle-aged rural females, who are largely employed in hand quality picking.

    b. Unskilled operators with limited time available for training in hand quality picking, which resulted in a significant quotidian effect. This effect was partially offset by analyzing each replication separately, and by the use of the Latin Square experimental plan described on page 28, Chapter V.

    c. Highly motivated by the experimental nature of the study.

    d. Prospective Industrial Engineers with considerable interest in investigations of this sort.

2. The Great Northern beans used as experimental objects in this investigation are not representative of all the products which are subject to manual quality picking.

3. Only two replications were performed.

4. Only one rate of flow was tested.

5. Only one density-speed combination was used.

6. Only one damage content was used.

7. The Pinto beans, which represented the damaged objects, are not identical in size and shape to Great Northern beans.

8. Only one belt width was used.

Conclusions.--The following conclusions are made from the experimental results within the limitations discussed above:

1. The first objective of this thesis - to determine if the picking method affected the net picking rate and the picking quality rate when other factors were at their optimum levels, was accomplished.

a. The analysis showed that the two "pick and throw" methods were superior to the "roll" method with regard to the net picking rate. Figure 9 shows that Method 2 was 4.7 and 5.2 pickouts per minute better than Method 1 for Replications 1 and 2 respectively; while Method 3 was 5.4 and 4.6 pickouts per minute better than Method 1 for Replications 1 and 2 respectively.

b. Insofar as the picking quality rate was concerned, the "roll" method was superior to either one of the "pick and throw" methods. Figure 10 shows that Method 1 had about the same picking quality rate for Replication 1, but during Replication 2 it was 1.2 and 1.6 good objects picked per minute better than Methods 2 and 3 respectively. This improvement in the picking quality rate was small in comparison to the increase in the net picking rate derived from using either of the "pick and throw" methods. Any industrial application of this conclusion should be tempered by the relative cost of the objects being picked.

c. There was no significant difference between the two "pick and throw" methods. The "pick and throw (multiple object)"

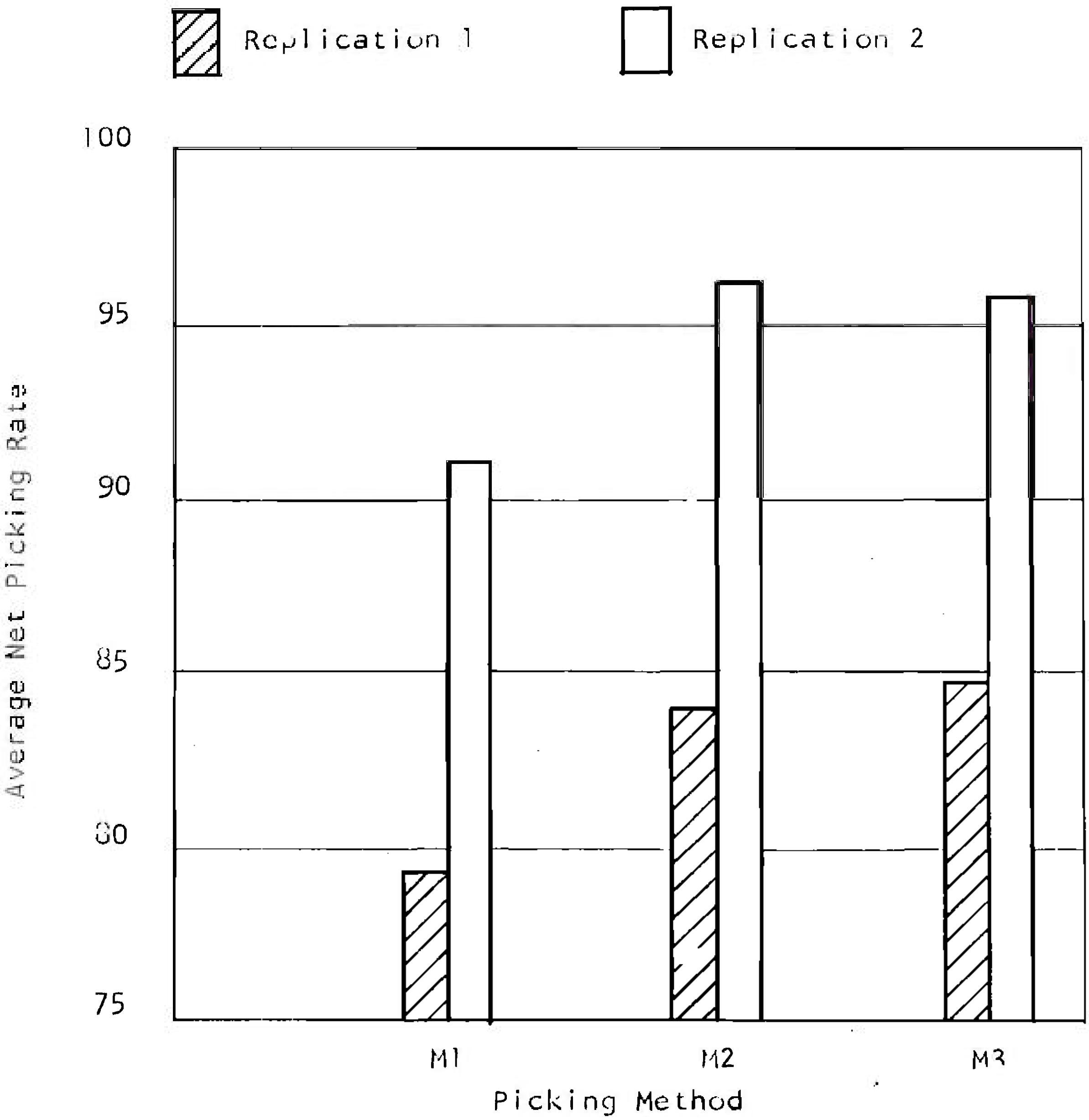

Figure 9. Average Net Picking Rate Versus Picking Method

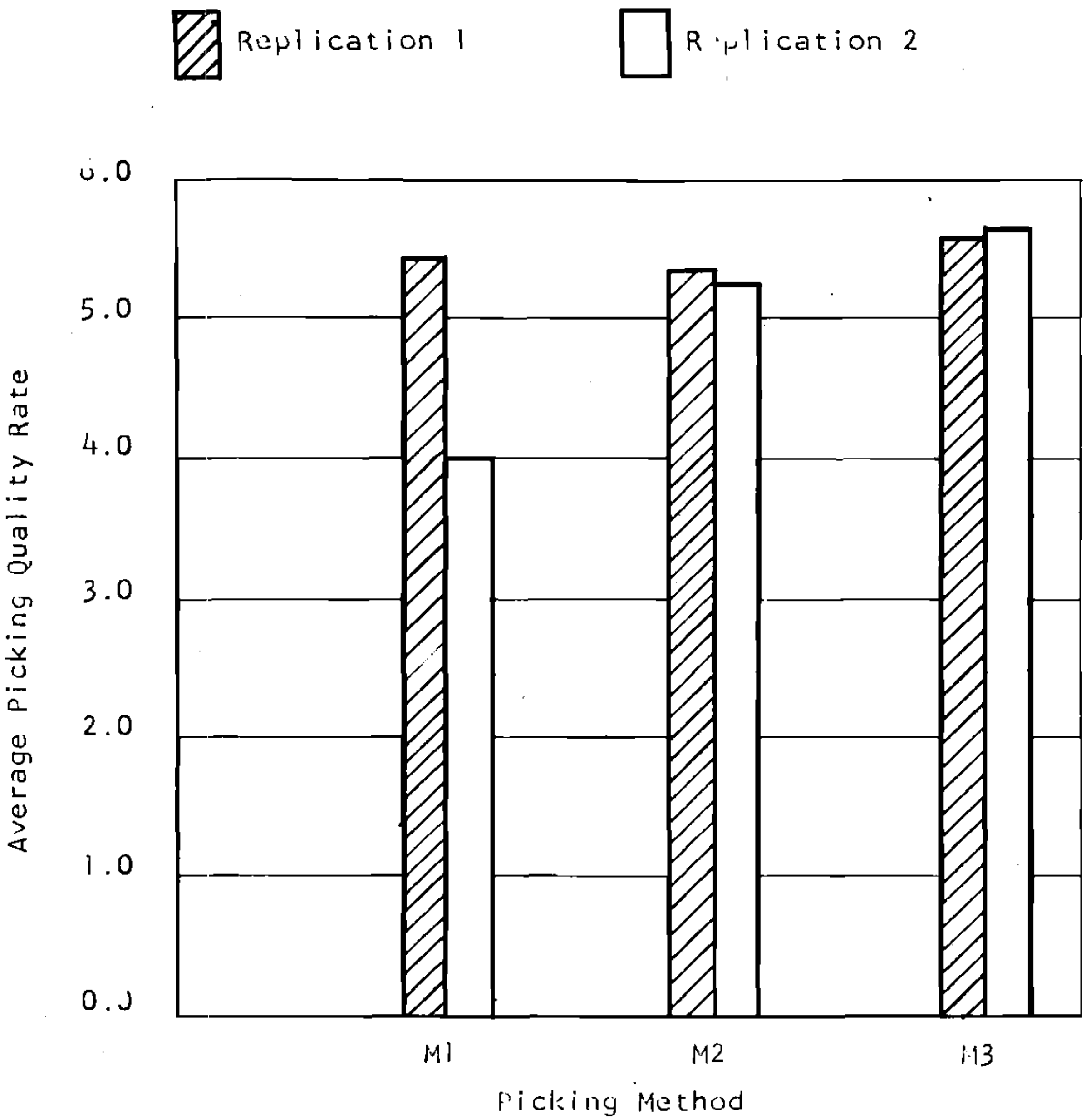

Figure 10. Average Picking Quality Rate Versus Picking Method

> method was slightly superior in overall performance to the "pick and throw (single object)" method.

2. The second objective, to determine if the picking position affected the net picking rate and the picking quality rate when other factors were at optimum levels, was accomplished. The analysis of the experimental results show (although not conclusively) that the picking positions have very little effect upon either the production or quality in manual quality picking. (See Figures 11 and 12). This conclusion also applies to a change in the direction of picking belt travel, which is the same as changing from one side of a belt to the other side.

3. The third objective was to determine if there was any relationship between an operator's performance and his dominant hand. It was found that left-handed operators picked as well at all positions as right-handed operators.

4. The final objective was to validate the use of certain aptitude tests to predict job success in manual quality picking. The correlation coefficient which was calculated was not significant at the .05 probability level. Therefore, it was concluded that the Purdue Pegboard Test scores were not a valid predictor of an operator's net picking rate for this particular group of experimental subjects.

The rate of flow, density-speed combination, and the damage content used in this investigation yielded production and quality results which were equal to or greater than that

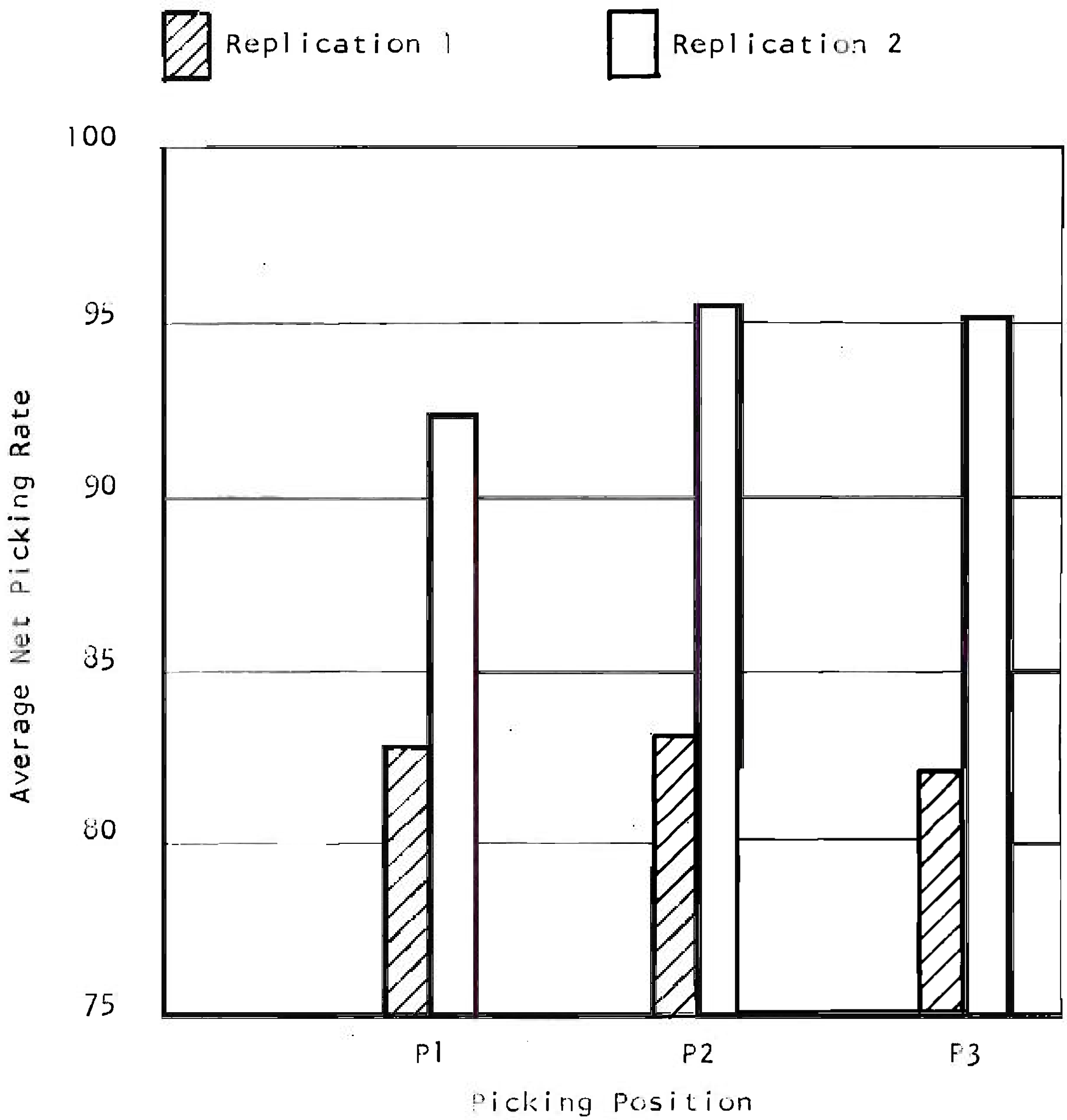

Figure 11. Average Net Picking Rate Versus Picking Position

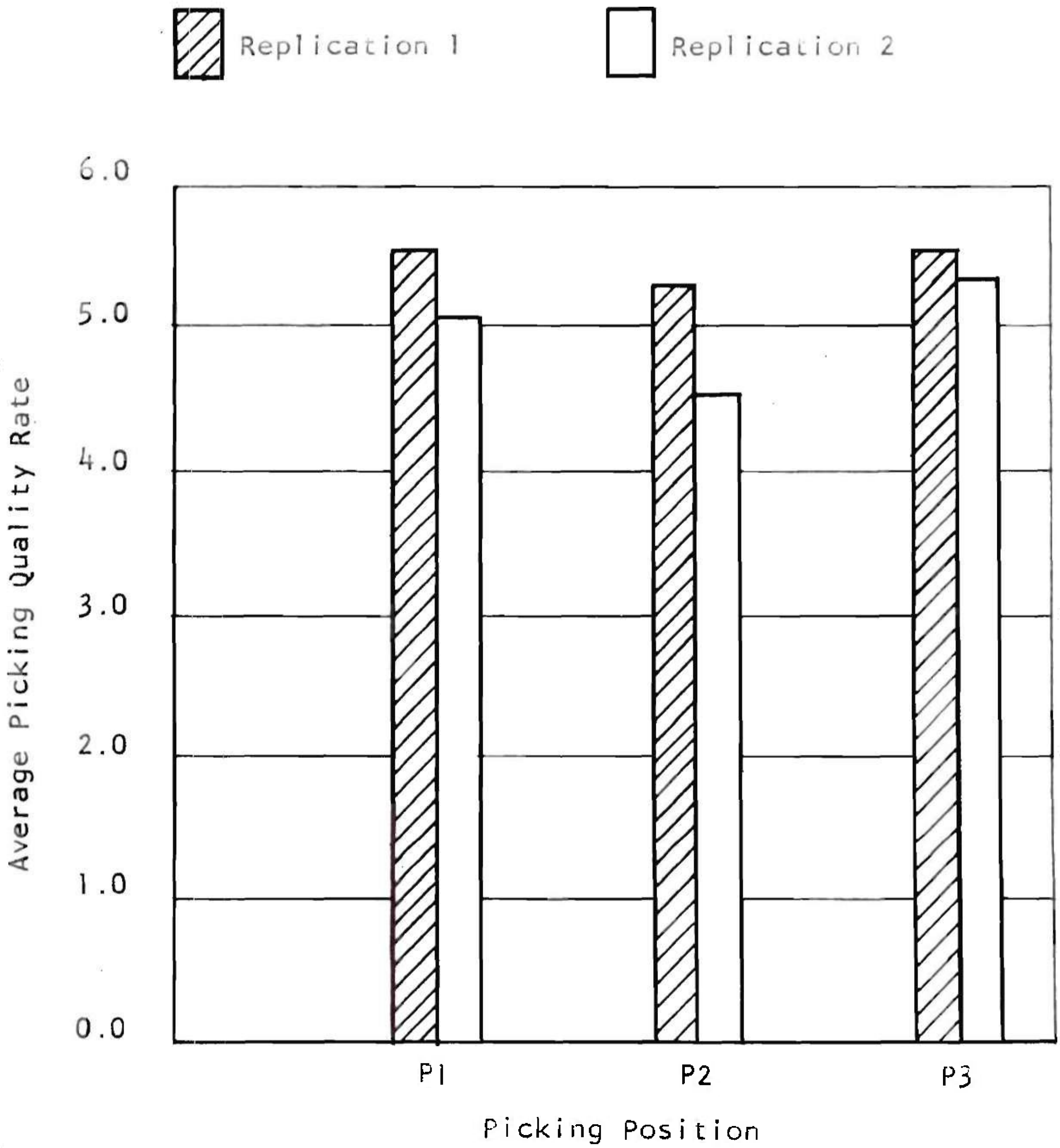

Figure 12. Average Picking Quality Rate Versus Picking Position

obtained by experienced workers employed in the manual quality picking industry.

Recommendations.--In view of the limitations, results, and conclusions of this study, it is recommended that any further study of hand quality picking be directed toward:

1. A more thorough analysis of the aptitude characteristics of hand quality picking with a view towards developing another aptitude test battery which will be valid for predicting success in the hand quality picking operation.

2. The refinement of the two "pick and throw" methods used in this investigation in order to determine whether or not one method is superior to the other method.

3. The use of a non-random pattern of experiments unless the investigator is able to have his subjects reach a plateau in their learning curves.

4. The further investigation of the effect of illumination on the belt and the color contrast of the objects with the belt color.

5. The use of objects other than Great Northern beans.

6. The effect of belt width.

7. The use of a larger and more representative sample of the people who do manual quality picking in industry.

Comments.--It is felt that this investigation together with those preceding it has brought to light information of value to industry. The plant manager who desires to use these results, with a full understanding of the relative importance of production versus quality, could set up his hand quality picking operation as follows:

1. Have all the operators pick from the side of the belt.

2. Require that all operators use one of the "pick and throw" methods.

3. Provide a minimum of 80 foot-candles of illumination.

4. Use a density-speed combination of approximately 25 per cent density at 43 feet per minute.

It is felt that the above operating conditions would produce the optimum results in any operation involving the manual quality picking of small objects.

APPENDIX

APPENDIX I

EXPERIMENTAL DATA

Table 7. Raw Scores on Battery of Tests

			Purdue Pegboard							
Operator	Average Net Picking Rate	Average Picking Quality Rate	Right Hand Test	Left Hand Test	Both Hands Test	R.& L. & B.H. Test	Assembly Test	Total Score	Moore Eye-Hand Coord. & Color-Match Test	Bausch & Lomb. Vis. Class. & Placement Test
1	94	3.7	18	17	13	48	45	93	50	OK
2.	93	1.4	19	18	16	53	48	101	55	OK
3	91	8.2	20	19	16	55	52	107	35	OK
4	87	10.0	20	20	15	55	49	104	60	OK
5	93	8.1	19	16	14	49	46	95	70	OK
6	92	4.7	15	15	13	43	43	86	15	OK *
7	82	4.9	15	17	14	46	44	90	55	OK **
8	82	1.9	16	17	12	45	42	87	15	OK
9	101	3.8	20	20	16	56	49	105	55	OK

* Defective visual acuity in right eye only
** Defective depth perception

Modal Score : 88.0
Mean Score : 92.5
Median Score : 92.0

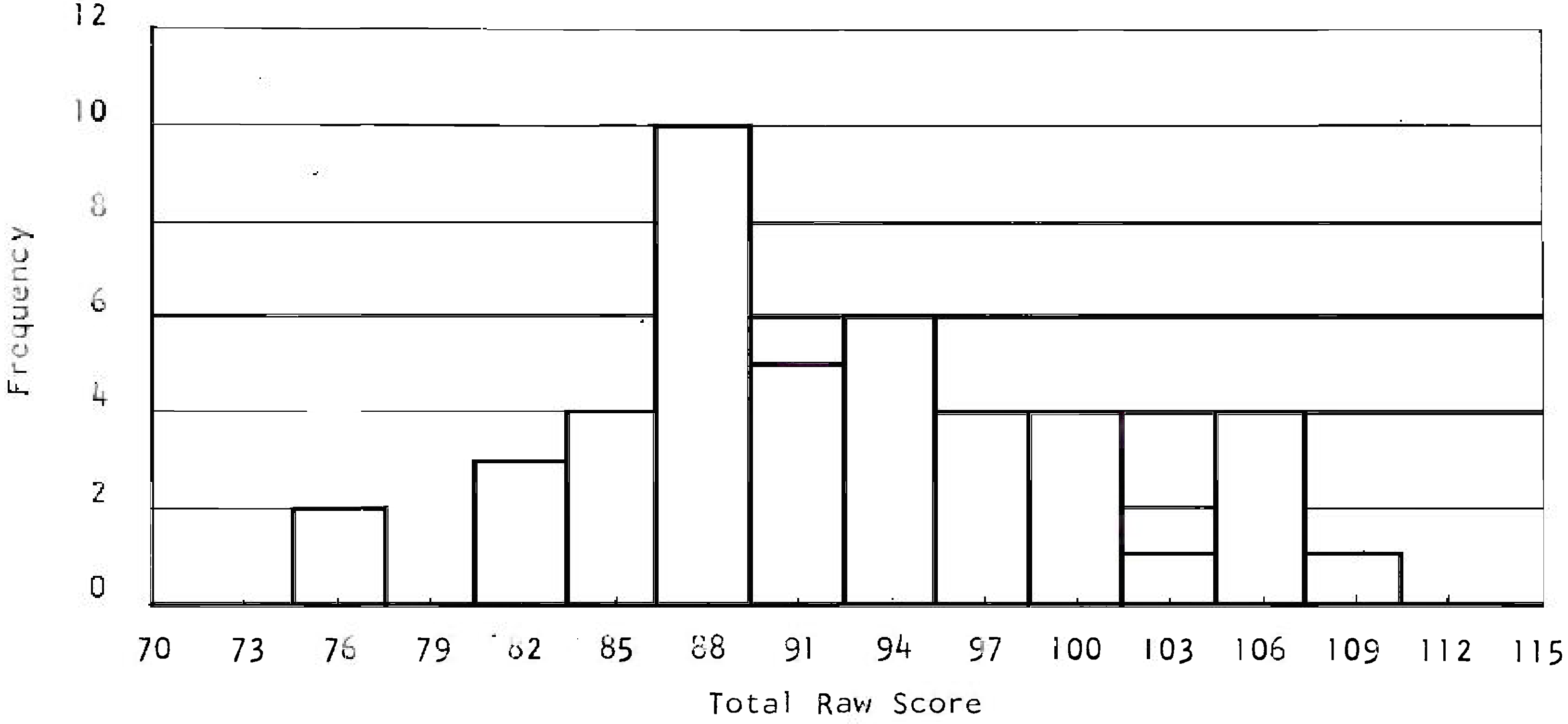

Figure 13. Histogram of Total Raw Scores of 44 Male Subjects on the Purdue Pegboard Tests (Right plus Left plus Both Hands plus Assembly Tests)

Legend to Tables 8 through 15

Operator 1	O 1
Operator 2	O 2
Operator 3	O 3
Operator 4	O 4
Operator 5	O 5
Operator 6	O 6
Operator 7	O 7
Operator 8	O 8
Operator 9	O 9
"Roll" Method	M 1
"Pick and Throw (Multiple Object)" Method	M 2
"Pick and Throw (Single Object)" Method	M 3
Right Side Position	P 1
Left Side Position	P 2
End Position	P 3
Replication 1	R 1
Replication 2	R 2

Table 8. Arrangement of Experimental Conditions

		SEQUENCE OF TEST RUNS								
		1	2	3	4	5	6	7	8	9
R1	01	M1P1	M2P1	M3P1	M2P2	M3P2	M1P2	M3P3	M1P3	M2P3
	02	M2P2	M3P2	M1P2	M3P3	M1P3	M2P3	M1P1	M2P1	M3P1
	03	M3P3	M1P3	M2P3	M1P1	M2P1	M3P1	M2P2	M3P2	M1P2
	04	M2P1	M3P1	M1P1	M3P2	M1P2	M2P2	M1P3	M2P3	M3P3
	05	M3P2	M1P2	M2P2	M1P3	M2P3	M3P3	M2P1	M3P1	M1P1
	06	M1P3	M2P3	M3P3	M2P1	M3P1	M1P1	M3P2	M1P3	M2P2
	07	M3P1	M1P1	M2P1	M1P2	M2P2	M3P2	M2P3	M3P3	M1P3
	08	M1P2	M2P2	M3P3	M2P3	M3P3	M1P3	M3P1	M1P1	M2P1
	09	M2P3	M3P3	M1P3	M3P1	M1P1	M2P1	M1P2	M2P2	M3P2
R2	01	M2P3	M3P3	M1P3	M3P1	M1P1	M2P1	M1P2	M2P2	M3P2
	02	M1P2	M2P2	M3P2	M2P3	M3P3	M1P3	M3P1	M1P1	M2P1
	03	M3P1	M1P1	M2P1	M1P2	M2P2	M3P2	M2P3	M3P3	M1P3
	04	M1P3	M2P3	M3P3	M2P1	M3P1	M1P1	M3P2	M1P2	M2P2
	05	M2P1	M3P1	M1P1	M3P2	M1P2	M2P2	M1P3	M2P3	M3P3
	06	M3P2	M1P2	M2P2	M1P3	M2P3	M3P3	M2P1	M3P1	M1P1
	07	M3P3	M1P3	M2P3	M1P1	M2P1	M3P1	M2P2	M3P2	M1P2
	08	M1P1	M2P1	M3P1	M2P2	M3P2	M1P2	M3P3	M1P3	M2P3
	09	M2P2	M3P2	M1P2	M3P3	M1P3	M2P3	M1P1	M2P1	M3P1

Table 9. Observed Number of Defective Objects Picked Per Minute Based upon a Three Minute Test Run.

		P1			P2			P3		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
R1	01	71.33	76.00	93.67	72.67	80.67	84.67	66.00	87.67	79.33
	02	84.33	86.00	93.00	80.67	93.67	91.67	80.67	87.33	93.33
	03	92.00	89.00	86.67	89.67	87.67	92.67	94.00	93.33	72.33
	04	71.67	79.67	76.67	77.33	84.67	77.33	71.33	85.67	79.00
	05	79.33	88.33	89.00	83.00	86.67	80.33	87.00	88.67	82.00
	06	73.67	75.67	84.33	77.00	85.00	81.67	75.67	74.33	79.67
	07	70.00	76.00	68.33	73.67	71.33	73.33	75.67	71.33	76.00
	08	76.33	74.67	88.33	72.33	79.00	85.00	76.33	72.67	84.00
	09	89.67	103.00	99.67	85.33	96.67	100.67	93.67	92.00	93.33
	Average	78.60	83.06	86.54	78.96	84.95	85.17	79.96	83.58	82.03
R2	01	83.67	98.00	100.00	102.00	114.00	118.33	97.67	91.67	101.33
	02	90.67	91.33	93.67	87.67	92.67	98.67	89.33	96.00	95.67
	03	103.67	94.67	83.33	97.33	95.33	93.00	102.00	104.00	99.00
	04	77.00	95.67	92.67	90.33	96.00	91.33	95.00	93.33	89.33
	05	94.67	100.67	95.00	88.00	105.00	98.33	98.00	100.33	100.33
	06	86.33	95.33	102.00	88.33	92.67	103.00	83.00	102.33	105.67
	07	94.00	90.67	91.00	91.67	89.33	89.67	94.00	94.67	90.00
	08	79.00	81.00	81.33	73.00	85.00	85.67	78.67	83.67	84.00
	09	94.00	99.67	106.67	102.67	113.33	98.33	98.67	105.33	96.33
	Average	89.13	94.02	93.87	91.13	98.05	97.27	92.83	96.72	95.64

Table 10. Observed Number of Good Objects Picked per Minute Based upon a Three Minute Test Run

		P1			P2			P3		
		M1	M2	M3	M1	M2	M3	M1	M2	M3
	01	2.3	1.3	5.7	0.7	5.3	2.0	5.0	3.7	8.0
	02	1.7	1.7	3.0	0.3	2.7	1.7	0.3	2.0	2.0
	03	5.3	7.0	5.3	9.7	9.0	4.7	3.3	10.0	4.7
	04	10.0	3.7	4.7	10.7	11.3	6.3	12.0	8.3	10.3
R1	05	9.0	5.7	11.0	5.7	7.7	9.0	7.3	8.0	9.3
	06	5.7	5.7	3.0	6.0	7.0	7.3	5.7	7.0	3.0
	07	15.0	5.7	26.0	5.7	4.7	7.0	5.0	3.7	3.7
	08	2.0	2.0	1.0	2.0	5.0	1.7	2.7	2.7	2.0
	09	1.0	3.7	2.3	2.0	4.7	3.7	4.0	5.7	2.7
	Average	5.77	4.05	6.82	4.75	6.37	4.82	5.84	5.67	5.07
	01	1.0	3.7	2.3	3.0	2.0	4.3	2.3	7.0	6.0
	02	0.7	2.3	2.0	0.3	0.0	1.0	0.7	1.3	0.7
	03	8.7	11.7	8.3	5.3	13.0	9.7	13.0	13.0	6.3
	04	11.0	13.3	11.3	14.3	7.7	16.3	8.0	8.0	13.0
R2	05	6.7	7.7	8.0	4.3	5.7	9.7	6.3	11.3	13.7
	06	3.0	6.7	4.0	1.3	3.7	3.7	2.0	4.3	5.0
	07	1.0	1.7	2.0	1.3	1.0	2.3	0.3	0.3	1.0
	08	1.0	1.3	2.0	1.7	0.3	1.3	1.0	3.7	1.3
	09	3.7	3.0	8.7	3.0	4.0	2.7	3.7	4.3	6.0
	Average	4.08	5.70	5.39	3.82	4.15	5.66	4.14	5.91	5.87

APPENDIX II

STATISTICAL ANALYSIS AND SAMPLE CALCULATIONS

ANALYSIS OF VARIANCE

In Table 11, the variable factors, the number of levels, the Model number of the factors, and the superscripts and subscripts designate the specific (or general) level of each factor in the analysis. Using the notation of Scheffe, the following equation was designed to express the mathematical model of the experiment:[65]

$$X_{ijk} = \mu + \alpha_j^M + \alpha_k^P + \alpha_{jk}^{MP} + a_i^0 + a_{ij}^{0M} + a_{ik}^{0P} + E_{ijk}$$

According to the superscripts of the model equation which show the possible main effects and interactions, Table 12 was constructed.

In Table 12 are given the equations from which the sums of squares were calculated. The actual sums of squares are shown in Tables 13, 14, and 15. The mean squares were found by dividing each sums of squares by their <u>degrees of freedom</u>. The expected mean squares were derived in order to determine which ratios of mean squares were suitable for testing the various null hypotheses with the Fisher F distribution.[66] For instance, the M x P interaction was tested against the Residual, whereas the M main effect was tested against the 0 x M interaction.

The P main effect was tested against the pooled mean square of the Residual and the 0 x P interaction. This pooled mean square was obtained by dividing their total sums of squares by the sum of their degrees of freedom. The O main effect and the two remaining interactions were tested against the Residual.

The ratios were compared with values taken from one-tail tables of F distributions according to their appropriate degrees of freedom. The ratios were rejected when their magnitudes were greater than the tabular values at the indicated probability levels. Rejection of the ratios meant that the factor was significant at that level of probability.

Table 11. Analysis of Variance

Factor	Super-script	Sub-script	Model	Symbol	No. of Levels
Operator	O	i	II	a_{i}^{O}	9
Method	M	j	I	α_{j}^{M}	3
Position	P	k	I	α_{k}^{P}	3
Operator x Method	O x M	ij	II	a_{ij}^{OM}	27
Operator x Position	O x P	ik	II	a_{ik}^{OP}	27
Method x Position	M x P	jk	I	α_{jk}^{MP}	9
Residual	R	ijk	II	ϵ_{ijk}	81

Table 12. Components of Variance, Part I

Factor	Degrees of Freedom	Components of Sums of Squares
O	8	$\Sigma_i S^2_{i..}/JK - S^2_{...}/IJK$
M	2	$\Sigma_j S^2_{.j.}/IK - S^2_{...}/IJK$
P	2	$\Sigma_k S^2_{..k}/IJ - S^2_{...}/IJK$
O x M	16	$\Sigma_{ij} S^2_{ij.}/K - \Sigma_i S^2_{i..}/JK - \Sigma_j S^2_{.j.}/IK + S^2_{...}/IJK$
O x P	16	$\Sigma_{ik} S^2_{i.k}/J - \Sigma_i S^2_{i..}/JK - \Sigma_k S^2_{..k}/IJ + S^2_{...}/IJK$
M x P	4	$\Sigma_{jk} S^2_{.jk}/I - \Sigma_j S^2_{.j.}/IK - \Sigma_k S^2_{..k}/IJ + S^2_{...}/IJK$
Residual	32	$\Sigma_{ijk} X^2_{ijk} - \Sigma_{ij} S^2_{ij.}/K - \Sigma_{ik} S^2_{i.k}/J - \Sigma_{jk} S^2_{.jk}/I +$
		$\Sigma_i S^2_{i..}/JK + \Sigma_j S^2_{.j.}/IK + \Sigma_k S^2_{..k}/IJ - S^2_{...}/IJK$
Total	80	$\Sigma_{ijk} X^2_{ijk} - S^2_{...}/IJK$

Table 13. Components of Variance, Part II - Replication 1

Factor	Expected Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Remarks
O	$\sigma_o^2 + MP\sigma_o^2$	3,436	8	429.5	$\frac{429.5}{21.6} = 19.9^{***}$	
M	$\sigma_o^2 + P\sigma_{OM}^2 + PO\sigma_M^2$	460	1	460	$\frac{460}{52.8} = 8.7^{**}$	M2+M3 Vs. M1
		5	1	5	$\frac{5}{52.8} = 0.1$	M2 Vs. M3
P	$\sigma_o^2 + M\sigma_{OP}^2 + MO\sigma_P^2$	22	1	22	$\frac{22}{17.3} = 1.3$	P1+P2 Vs. P3
		2	1	2	$\frac{2}{17.3} = 0.1$	P1 Vs. P2
O × M	$\sigma_o^2 + P\sigma_{OM}^2$	844	16	52.8	$\frac{52.8}{21.6} = 2.4^{*}$	
O × P	$\sigma_o^2 + M\sigma_{OP}^2$	137	16	8.6	$\frac{8.6}{21.6} = 0.4$	

* Significant at the .05 Probability Level
** Significant at the .01 Probability Level
*** Significant at the .001 Probability Level

Table 13. Components of Variance, Part II, Replication I (Continued)

Factor	Expected Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Remarks
		49	1	49	$\frac{49}{21.6} = 2.3$	M1 + M2 + M3 Vs P1 + P2 + P3
		36	1	36	$\frac{36}{21.6} = 1.7$	M2 + M3 Vs P1 + P2 + P3
M x P	$\sigma_o^2 - 0\sigma_{MP}^2$					
		0	1	0	0	M1 + M2 + M3 Vs P1 + P2
		25	1	25	$\frac{25}{21.6} = 1.2$	M2 + M3 Vs P1 + P2
Residual	σ_o^2	692	32	21.6		
Total		5,708	80	1,081.5		

* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

Table 14. Components of Variance, Part II - Replication 2

Factor	Expected Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Remarks
O	$\sigma_o^2 + MP\sigma_o^2$	2,721	8	340.1	$\frac{340.1}{22.3} = 15.3^{***}$	
M	$\sigma_o^2 + P\sigma_{OM}^2 + PO\sigma_M^2$	420	1	420	$\frac{420}{53.9} = 7.8^{**}$	M2+M3 Vs M1
		7	1	7	$\frac{7}{53.9} = .1$	M2 Vs M3
P	$\sigma_o^2 + M\sigma_{OP}^2 + MO\sigma_P^2$	22	1	22	$\frac{22}{27} = .8$	P1+P2 Vs P3
		125	1	125	$\frac{125}{27} = 4.6^{*}$	P1 Vs P2
O x M	$\sigma_o^2 + P\sigma_{OM}^2$	862	16	53.9	$\frac{53.9}{22.3} = 2.4^{*}$	
O x P	$\sigma_o^2 + M\sigma_{OP}^2$	585	16	36.6	$\frac{36.6}{22.3} = 1.6$	

* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

Table 14. Components of Variance, Part II - Replication 2 (Continued)

Factor	Expected Mean Squares	Sums of Squares	Degrees of Freedom	Mean Squares	F-Test	Remarks
M x P	$\sigma_o^2 - 0\sigma_{MP}^2$	23	1	23	$\frac{23}{22.3} = 1.0$	M1 + M2 + M3 Vs P1 + P2 + P3
		1	1	1	$\frac{1}{22.3} = 0.0$	M2 + M3 Vs P. + P2 + P3
		9	1	9	$\frac{9}{22.3} = 0.4$	M1 + M2 + M3 Vs P1 + P2
		0.7	1	0.7	$\frac{0.7}{22.3} = 0.0$	M2 + M3 Vs P1 + P2
Residual	σ_o^2	712	32	22.3		
Total		5,488	80	1,054.6		

* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

Table 15. Components of Variance - Picking Quality Rate

			Replication 1			Replication 2		
Factor	Expected Mean Squares	Degrees of Freedom	Sums of Squares	Mean Squares	F-Test	Sums of Squares	Mean Squares	F-Test
O	${}^{2}_{o} + MP\,{}^{2}_{O}$	8	530	66.3	10.2***	1,091	136.3	31.7***
M	${}^{2}_{o} + P\,{}^{2}_{OM} + PO\,{}^{2}_{M}$	2	2	1	.1	39	19.5	4.9**
P	${}^{2}_{o} + M\,{}^{2}_{OP} + MO\,{}^{2}_{P}$	2	1	.5	.1	5	2.5	.6
O x M	${}^{2}_{o} + P\,{}^{2}_{OM}$	16	174	10.9	1.7	53	3.3	.8
O x P	${}^{2}_{o} + M\,{}^{2}_{OP}$	16	283	17.7	2.7**	55	3.4	.8
M x P	${}^{2}_{o} + O\,{}^{2}_{MP}$	4	51	12.8	2.0	12	3.0	.7
Residual	${}^{2}_{o}$	32	209	6.5		138	4.3	

* Significant at the .05 probability level
** Significant at the .01 probability level
*** Significant at the .001 probability level

APPENDIX III

MISCELLANEOUS

Economy Study of the Effect of Good Objects in The Total Pickouts upon the Costs of Manual Quality Picking

Analysis of Material Cost

Value of edible peanuts	$ .20 per pound
Value of defective peanuts used for oil processing	.11 per pound
Loss in value of good peanuts placed in the pickouts	.09 per pound
Average rate of good objects placed in the pickouts	5.2 kernels per minute*
Average number of kernels per pound of Spanish peanuts	1,500
Assumed working time per day	8 hours
Loss in value due to good peanuts in the total pickouts per day per operator	$ .15

This cost is relatively unimportant. However, if the edible product value was to increase substantially or if the by-product value was to decrease considerably; then the above loss might be significant. This is the case when pecans or walnuts are hand-quality picked instead of peanuts.

There is another and more important cost arising from the operator picking a good object instead of a defective one. That is the cost of the labor which is wasted when these errors occur.

Analysis of Labor Cost

Minimum wages per hour	\$1.00 per hour
Minimum working hours per day	8 hours
Average total pickouts per minute	93.7 kernels*
Time to pick one peanut	.011 minute
Cost of picking one peanut	\$ .00019
Average rate of good objects placed in the pickouts	5.2 kernels per minute*
Cost of picking good objects per day per operator	\$ .47
Total cost per day per operator due to placing good peanuts in the pickouts	\$ .62

* Based on data from this investigation

DATA SHEET

Operator: Doe, John J. Date: June 1, 1956

Code No : 01 Replication No: 1

Time : 2:10 - 3:00 Foot Candles : 70

Elbow Height (from floor) 46 in. Glasses: ~~Yes~~ No

~~Right~~ or Left-Handed Remarks: None

Run No.	Condition	Total Pick-outs	Total Errors	Net Pick-outs	Total Pick-outs/min.	Errors per/min.	Net Pick-outs/min.
1	M2P2	221	20	201	73.67	6.67	67.00
2	M3P2	243	27	216	81.00	9.00	72.00
3	M1P2	177	13	164	59.00	4.33	54.67
Sub-Total		641	60	581			
4	M3P3	218	32	186	72.67	10.67	62.00
5	M1P3	155	7	148	51.67	2.33	49.34
6	M2P3	221	35	186	73.67	11.67	62.00
Sub-Total		594	74	520			
7	M1P1	188	10	178	62.67	3.33	59.34
8	M2P1	208	15	193	69.33	5.00	64.33
9	M3P1	239	18	221	79.67	6.00	73.67
Sub-Total		635	43	592			
Total		1870	177	1693			
Average		207.78	19.67	188.11	69.26	6.55	62.70

Experimental Conditions

Methods

M1 - "Roll" method
M2 - "Pick and Throw (Multiple)" method
M3 - "Pick and Throw (Single)" method

Positions

P1 - Right Side
P2 - Left Side
P3 - End

Figure 14. Sample Data Sheet

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